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**THE MICROSCOPIC ORIGINS OF TOUGHNESS AND IMPACT
RESISTANCE IN METAL-REINFORCED CERAMICS**

Final Report

Contract No. DAAL03-88-C-0027

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19. ABSTRACT (Continue on reverse if necessary and identify by block number) It has been shown that fracture resistance in the metal-reinforced ceramics WC/Co, Al ₂ O ₃ /Al, and B ₄ C/Al arises from both plasticity and crack bridging. The theoretical basis has been laid for interpreting high resolution measurements of displacement fields and crack opening profiles to deduce the proportion of toughening due to each of these mechanisms in detail. Preliminary analysis accounting for plasticity alone has been presented for data for WC/Co. Various theoretical results have been obtained concerning the inverse problem of deducing bulk plastic strain fields from surface displacement measurements and deducing bridging tractions from measured crack opening profiles.				
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1.0 THE PROBLEM STUDIED

Our goal was to understand the mechanics of crack resistance and R-curve effects in metal-reinforced ceramics under both static and dynamic loading. The materials studied were WC/Co, Lanxide Al_2O_3/Al , and B_4C/Al . When the program was prematurely terminated (after one year's funding), we had achieved significant progress for static loading, as detailed below; but dynamic loading experiments had not yet begun.

2.0 IMPORTANT RESULTS

2.1 Theory

We published several papers on the interpretation of experimental measurements of plastic strain and crack opening displacements. We have shown how (1) crack bridging can be quantified by measuring the crack opening displacement under load,¹ and (2) how bulk plastic strain fields can be deduced from measurements of surface displacement fields.²⁻⁶ Our theories form a sufficient basis for assessing the relative importance of plasticity and crack bridging (the main mechanisms of toughening in cermets) from appropriate experiments.

2.2 Crack Resistance in WC/Co, Al_2O_3 , and B_4C/Al

Using high resolution displacement mapping carried out with our own unique system "HASMAPP" (High Accuracy Strain MAPper), we have shown that plastic zones much larger than previously expected exist in all three of these cemented carbides. Estimates of the crack tip shielding due to plasticity in WC/Co specimens show that a substantial fraction of the fracture toughness is due to the plastic zone.⁷ Reduced zone sizes were observed in regions of rapid crack growth, implying that the dynamic fracture toughness may be smaller than the static toughness. We also directly observed bridging ligaments in the crack wake, confirming the importance of crack bridging as a second toughening mechanism.



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3.0 OUTLOOK

We are using other funding to complete the analysis of further data taken in this program on $\text{Al}_2\text{O}_3/\text{Al}$ and $\text{B}_4\text{C}/\text{Al}$. The data are qualitatively similar to those for WC/Co . We are now calculating the contributions to toughness of both plasticity and crack bridging, using HASMAP's measurements of plastic strains and crack opening displacements. Our analysis is based on the theory described in Section 2.1. When this work is published, due acknowledgement will be accorded this contract for data collection. We feel that this work will be a major advance in understanding the micromechanics of metal-reinforced ceramics.



4.0 PUBLICATIONS UNDER THIS CONTRACT

1. B.N. Cox and D.B. Marshall, "The Determination of Crack Bridging Forces," Int. J. Fracture, in press.
2. Z. Gao and T. Mura, "Nondestructive Evaluation of Interfacial Damages in Composite Materials," Int. J. Solids and Structures 25, 901-16 (1989).
3. Z. Gao and T. Mura, "On the Inversion of Residual Stresses from Surface Displacements," J. Appl. Mech., in press.
4. Z. Gao and T. Mura, "Fracture Toughness Enhancement Due to Particle Transformation," IUTAM Symp. on Inelastic Deformation of Composite Materials, June 1990, Troy, NY, ed. G.J. Dvorak.
5. Z. Gao and T. Mura, "Nonelastic Strains in Solids - An Inverse Characterization from Measured Boundary Data," by Z. Gao and T. Mura, submitted to Mech. of Materials.
6. T. Mura and Z. Gao, "Nonlinearity of Inverse Problems," Proc. 7th Army Conf. on Applied Math. and Computing, ed. T.C. Chandra (1989).
7. D.B. Marshall, W.L. Morris, B.N. Cox and M.S. Dadkhah, "Toughening Mechanisms in Cemented Carbides," J. Amer. Ceram. Soc., in press.



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